data of C_2 before publication, though the intended calculations were not carried out in detail until years later after conclusive experimental information had become available. The support by the National Science Foundation is kindly acknowledged.

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TOTAL RADIATION WIDTHS FOR s-WAVE AND p-WAVE NEUTRON CAPTURE IN Nb^{93}†

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(Received 26 August 1963)

The recent successful use of resonant-capture γ-ray spectra to assign parities to resonances[1] has made possible for the first time a systematic study of resonance parameters for s-wave and p-wave neutron capture by direct measurement of individual resonances. Of these parameters the total radiation widths for s-wave and p-wave resonances, which we denote as $(\Gamma_\gamma)_s$ and $(\Gamma_\gamma)_p$, are of particular interest as a source of information about the dependence of the electric-dipole radiation strength on the parity of highly excited radiating states. Furthermore, accurate values of these widths can be used in analyzing measurements of total capture cross sections to obtain more reliable estimates of the s-wave and p-wave neutron strength functions. Until now, the usual assumption[2,3] has been that $(\Gamma_\gamma)_s = (\Gamma_\gamma)_p$; but the results of measurements on resonances in Nb^{93}, presented in this note, demonstrate a marked difference between these quantities.

An accurate measurement of Γ_γ is possible for many resonances in Nb^{93} because in each case the neutron width Γ_n is much smaller than the total width Γ. Consequently, Γ_γ can be determined precisely by assuming $g=0.5$ and subtracting $2g\Gamma_n$ from measured value of the total width. The values of Γ and $2g\Gamma_n$ for resonances in Nb^{93} are shown in Table I. They were obtained from transmission measurements on niobium plates of thicknesses 0.00148, 0.0709, 0.0178, and 0.284 atom per barn. The samples, 99.9% pure, contained a 0.1% impurity of tantalum which produces resonance structure of importance only near the 35.9-eV resonance. Effects of this structure were included in the analysis. The resonances at 119 eV and 194 eV were measured with a time-of-flight resolution width of 12 nsec/m and the remaining cases measured with a resolution of 24 nsec/m by use of the Argonne fast chopper. Typical thick-sample transmission data are shown in Fig. 1 for two resonances whose parameters are dis-

Table I. Parameters for neutron resonances in niobium. The results for resonances at 35.9 eV and 42.2 eV are in agreement with those of Saplakoglu, Bollinger, and Coté.[a] Because their results for resonances at higher energies are based on an assumed value $\Gamma_\gamma = 0.22$ eV for the radiation width, they will be subject to large corrections. The value of Γ_γ for the level at 194 eV is in strong disagreement with an older value of 0.34 ± 0.06 eV obtained in an indirect measurement by Rae.[b]

E_0 (eV)	Parity	Γ (10^{-3} eV)	$2g\Gamma_n$ (10^{-3} eV)	Γ_γ (10^{-3} eV)
35.9	⋯	215 ± 40	0.12 ± 0.01	215 ± 40
42.2	⋯	260 ± 20	0.09 ± 0.01	260 ± 20
94.3	⋯	215 ± 50	0.34 ± 0.03	215 ± 50
106	+	96 ± 50	0.05 ± 0.01	96 ± 50
119	+	113 ± 20	0.58 ± 0.06	113 ± 20
194	+	175 ± 25	41.7 ± 4	133 ± 30

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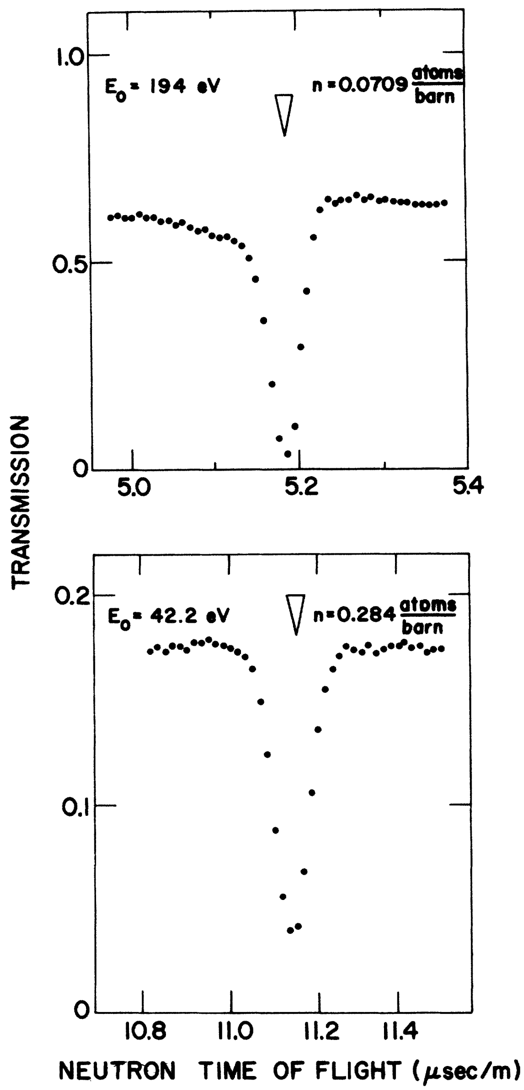

FIG. 1. Thick-sample transmission data for resonances at 42.2 eV and 194 eV. The resonance at 194 eV, identified as s-wave from capture γ-ray studies, shows the typical asymmetric shape expected for s-wave capture. The capture spectrum for the 42.2-eV resonance indicates p-wave capture. The triangles represent the appropriate resolution function for each measurement. The statistical accuracy of individual points is approximately their diameter. For all sample thicknesses, data of this quality were obtained in 36 hours or less of running time.

cussed in detail below. The high statistical accuracy of the data, an order of magnitude higher than that of previous measurements, was made possible by a new neutron detection system[4] consisting of six boron-loaded scintillation units. The high-efficiency and large area (600 cm^2) of this system result in exceptionally high counting rates.

The resonances at 35.9 eV and 42.2 eV were analyzed by shape analysis and the remainder by conventional area methods. The parity assignments shown in Table I were based on studies of the single-photon capture spectra and have already been reported.[1] Briefly, assignment is made by measuring the total intensity of transitions from the capture state to a group of low-lying states of predominantly positive parity. On this basis the resonances can be divided into two groups characterized by markedly different total intensities, the ratio of the mean intensities for the two groups in Nb being approximately 5. The group with the larger mean intensity is interpreted as consisting a p-wave resonances.

For s-wave resonances in other nuclides, with few exceptions, the total radiation width has been observed to be constant from level to level.[5] However, by using the parity assignments to analyze the data for niobium, we obtain $(\bar{\Gamma}_\gamma)_p = 0.230$ eV and $(\bar{\Gamma}_\gamma)_s = 0.114$ eV for the two classes of resonances. Within each group the measured radiation widths are the same within experimental error. Therefore, the results must be interpreted as indicating a definite variation of Γ_γ with neutron angular momentum.

If the discussion is restricted to electric-dipole radiation, the total radiation width for a resonance of parity Π and spin J will be given by the relation

$$\Gamma_\gamma = \int_0^U \Gamma(U,E)\rho_{-\Pi}(E)dE$$

$$= \int_0^U \left\langle \frac{\Gamma(U,E)}{D_{J,\Pi}(U)} \right\rangle \frac{\rho_{-\Pi}(E)}{\rho_{J,\Pi}(U)} dE,$$

$$\rho_{-\Pi} = \sum_{J'=J-1}^{J+1} \rho_{J',-\Pi}(E), \qquad (1)$$

where $\rho_{J,\Pi}(E)$ is the density of states of spin J and parity Π, $D_{J,\Pi}(E)$ is the spacing of these states, and $\Gamma(U,E)$ is the partial width for a primary transition of energy E from a state at excitation U. A dependence on Π of either the strength function $\langle \Gamma(U,E)/D_{J,\Pi}(U)\rangle$ or the ratio of level densities in the integrand of Eq. (1) will explain the difference between $(\bar{\Gamma}_\gamma)_p$ and $(\bar{\Gamma}_\gamma)_s$. However, Nb^{94} is an odd-odd nucleus with an appreciable mixture of shell-model configurations

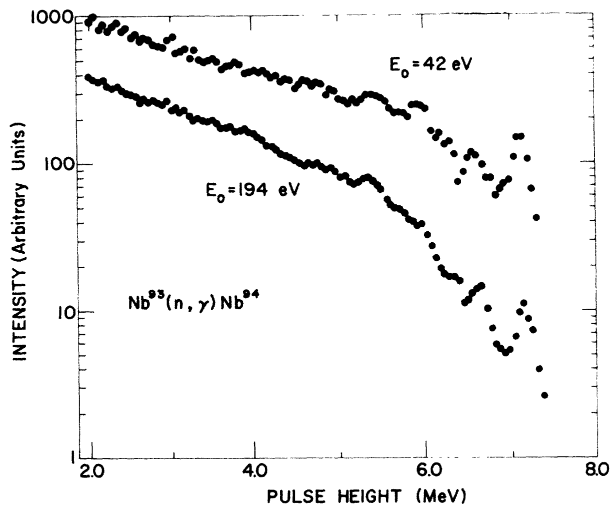

FIG. 2. Gamma-ray spectra observed in an 8- ×6-inch NaI crystal from capture in resonances in Nb^{93} at 42.2 eV and 194 eV. The resonance at 194 eV is excited by s-wave neutrons and the one at 42.2 eV by p-wave neutrons. The absolute intensities of high-energy primary transitions in the 194-eV spectrum were estimated by comparison with the thermal capture spectrum which was observed under identical conditions. The intensities used for transitions observed in thermal capture were measured by G. A. Bartholomew and B. B. Kinsey, Can. J. Phys. 31, 1025 (1953).

of both parities at low excitation. For excitations >2 MeV in this nuclide, even an extreme pairing model of nuclear excitation[6] does not predict a significant difference in the density of states of opposite parity. Thus, the ratio $\rho_{-\Pi}(E)/\rho_{J,\Pi}(U)$ should be independent of Π for $E > 2$ MeV. Although little experimental information is available for $E < 2$ MeV, states of positive parity are expected to dominate. The possibility that the resulting variation in $\rho_{-\Pi}(E)/\rho_{J,\Pi}(U)$ could account for the observed difference in Γ_γ has been investigated here for the resonances at 42.2 eV and 194 eV by determining the intensities of primary transitions to levels within 2 MeV of the ground state. Analysis of the capture spectra (Fig. 2) yields a difference of no more than 0.012 eV for the sum of the partial widths of the transitions, yet the observed difference in Γ_γ is 0.127 eV. If these conclusions are accepted, the results of this measurement suggest that the dipole strength function is significantly larger for highly excited states of negative parity in Nb^{94}, than for similar states of positive parity.

Until recently, a Weisskopf single-particle estimate was used for $\langle\Gamma(U,E)/D_{J,\Pi}(U)\rangle$. In view of the contradictions which result from this approach, Axel[7] has recently re-emphasized that a more reasonable estimate can be obtained for a given nuclide by extrapolating the photon absorption cross section in the region of the giant-dipole resonance to the neutron binding energy to obtain the strength function. Neither of these approaches explains a parity dependence of the dipole strength function. However, such a variation has been proposed by Cameron.[8] He observes that the wave functions for the initial states will contain a large admixture of an appropriate single-particle neutron wave function for nuclei near peaks in the s-wave or p-wave neutron strength function. This will enhance the dipole strength from these states. On this basis, the radiation from p-wave resonances should be enhanced for Nb^{93}, which is at the peak in the p-wave neutron strength function. This is the first experimental indication of such an effect.

The author gratefully acknowledges valuable discussions with Dr. L. M. Bollinger, Dr. P. A. Moldauer, and Dr. N. Rosenzweig.

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†Work performed under the auspices of the U. S. Atomic Energy Commission.

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